



## MATERIAL SELECTION FOR MICROSTRIP ANTENNA USING CRITIC-MAICRA INTEGRATION AS A PRACTICAL APPROACH

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### ABSTRACT

Selection of suitable material is a critical step in microstrip antenna design. Dielectric constant, thermal expansion coefficient, conductivity, mechanical properties and weight are the leading material properties in material selection. In addition to these factors, environmental impact, cost and size are among the most prominent design criteria. In this study a multi criteria decision making (MCDM) structure for material selection analysis in microstrip antenna production, is proposed. In this context, CRITIC-MAIRCA integration which is one of the MCDM approaches utilized to determine the best material for microstrip antenna. Dielectric constant, loss tangent and thermal expansion coefficient criteria are considered to select the best among eighteen different materials. The impact of each criterion on selection process is computed via CRITIC. To rank the alternatives taking into account criteria weights, MAIRCA was utilized. As a result, BaSrTi<sub>2</sub>O<sub>6</sub> (bulk form) was found to be the best material for microstrip antenna manufacturing. This study provides an initial insight to practical material selection.

**Keywords:** Microstrip antenna, Material selection, MCDM, CRITIC, MAIRCA

## 1. INTRODUCTION

An antenna can be described as the device that has the capability to receive and radiate electromagnetic waves efficiently as required [1]. Antennas can be categorized in two groups; wire-type (yagi-uda, helical and long-period antennas) and aperture-type (horn, slot, micro strip, reflector and lens antennas) according to their physical structures [1].

The design of an antenna should primarily include the selection of suitable material [2]. Antennas should be constructed by conducting materials, low loss dielectric materials or their combination [1]. Antenna efficiency is directly related to the *conductivity* of the material so conductive materials are most commonly used in antenna production [1]. The bandwidth which is denoted as ( $\Gamma$ ) is an important parameter that refers to the frequency range (between  $f_u$  and  $f_l$ , upper and lower frequencies, respectively), while the desired antenna performance firmly depends on the maximum allowable reflection coefficient ( $\Gamma_{max}$ ) [3]. In addition, the fractional bandwidth (FBW) can be expressed as [3]:

$$FBW = \frac{f_u - f_l}{f_c} \quad \text{where center frequency } (f_c) \text{ is } f_c = \frac{f_u + f_l}{2}$$

Other parameters, apart from the electrical properties, that must be considered during material selection among conducting materials for antenna design are; *mechanical properties, environmental factors, cost, size and weight* [1, 2]. The material should possess mechanical strength to preserve its initial shape [1]. In addition, the material should be stable against environmental conditions and resistant to oxidation and erosion [1]. Manufacturing cost and the weight of the material should be as minimum as possible [1].

Copper, brass (copper-zinc alloy), bronze (copper-tin alloy) and aluminum are among widely used conducting materials to build antennas [1]. However metal mates cause a problem named galvanic corrosion that must be considered during antenna construction [1]. Utilization of the same metal, inclusion of absorbent washers or insulating corrosive metals from each other are a couple of methods to prevent galvanic corrosion

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[1]. Composites are becoming prevalent for antenna production due to their combined effects [1]. For instance, polycarbonate/acrylonitrile butadiene styrene (PC/ABS) is used to make mobile phone antenna thanks to the combined effect of heat resistance of polycarbonate and processability of ABS [1].

*Dielectric* materials are used to cover a metal antenna or to function as a dielectric antenna itself [1]. The material of dielectric antenna should possess a *high dielectric constant and a low dielectric loss* [3, 4]. Using a material with high dielectric constant would have the advantage of designing a compact antenna [5] since there will be frequency shortening effect of wave that is transmitted in the dielectric material [4]. Ceramic materials are very convenient for their high dielectric constant and low dielectric loss, but machining and fabrication problems arise due to their brittle nature [5]. Therefore, ceramics are preferred as reinforcement element in polymeric matrix and composites, which are good alternatives for antenna materials. In addition, arbitrary selection of dielectric constant is not an option in ceramic materials that have been conventionally used as antenna materials whereas, dielectric ceramic powder amount can be adjusted in rubber matrix so that the relative dielectric constant can be established [4]. The volume percentages of the polymeric matrixes are in between 10% and 70% and the particle sizes are in the range of 0.2  $\mu\text{m}$  to 10  $\mu\text{m}$  [6]. Dielectric materials have significant influence on the mechanical, thermal and electrical properties of the microstrip antennas so, dielectric material selection is a critical point in design phase[3]. Dielectrics built by polystyrene foam or honeycomb structures lead to lower dielectric constant (between 1 and 2) whereas fiberglass reinforced polytetrafluoroethylene (PTFE) results in relative dielectric constant (between 2 and 4) [3]. In addition, ceramic, quartz and alumina can possess higher dielectric values [3].

Magneto-dielectric materials having dielectric constant ( $\epsilon$ ) and magnetic permeability ( $\mu$ ) values higher than 1, and low loss values are deemed as good alternative materials for antenna construction [7]. For instance, composite substrates composed of magnetic inclusions dispersed in dielectric matrix materials are designed [8], as composites have superior properties like high relative permeability of composites over magnetic materials [8]. On the other hand, alumina ceramic substrates have high dielectric constant values in the range of 9.7 and 10.3 [9]. In addition, there are some commercial substrates like K 6098 teflon / glass, RT / duroid 5880 PTFE (micro glass fiber + PTFE) and epsilam-10 ceramic filled Teflon **that** have dielectric constants of 2.5, 2.2 and 10, respectively [9].

Liquid crystal polymer (LCP) material is an alternative for multilayer antenna arrays due to its low dielectric constant, low loss tangent and low cost in addition to its flexibility that makes antenna deployment in space easier and leads to easy flexing, rolling up and deployment of large sheets of antenna arrays [10]. Moreover, it possesses improved barrier properties and permeability values as in the case of glasses and ceramics [10]. In addition, the changes in relative dielectric constant and loss tangent depending on the environment can be avoided due to low water absorption of LCP which provides increased stability in different environments [11].

*Dielectric constant* ( $\epsilon$ ) of a material and its tolerance are important performance criteria for antenna design [9]. The required accuracy of the change in relative dielectric constant is  $\pm 0.04$  [9]. In addition, the *thickness* variation of the substrate has an effect on the frequency, this effect is minor compared to the effect of dielectric tolerance [9]. *Thermal expansion coefficient* is another critical parameter for material selection and it must be lower than  $50 \times 10^{-6} / ^\circ\text{C}$  [9]. Particle reinforcing of polymers is an effective way to decrease the coefficient of thermal expansion [12].

As mentioned before, composite materials have been preferably used as antenna material. For instance, woven glass mat or small glass fibers that are impregnated by PTFE composites are known as excellent antenna alternative materials due to their improved mechanical and electrical properties [9,13]. However, PTFE has a high coefficient of thermal expansion (above 100 ppm/ $^\circ\text{C}$ ) [13]. On the other hand, glass fiber-PTFE matrix composite can be applied on complex surfaces since the fibers are small and the polymer matrix is flexible [9]. The reinforcement material in PTFE can also be ceramic [9,13] that will end up with low loss, good chemical resistance, machinability and dimensional stability and low dielectric constant [13]. The dielectric constant depends on the electrical field orientation if the

reinforcement element is in the form of fiber orientated [9]. The amount of this effect is related to the percent of fiber in polymer and the difference in dielectric constants between the fiber orientation [9].

As stated above, each material has different characteristics and this makes it difficult to select the most suitable material for the microstrip antenna. In this context, this study proposes an integrated approach with a multi-criteria (MCDM) structure for material selection. This approach, which does not depend on experimental study, aims to provide a more practical solution for material selection. In MCDM problems, there are more than one feasible alternatives and these alternatives must be evaluated according to more than one criteria. Criteria are the performance standards for alternatives. Firstly, the weight which can be defined as the impact level of each criterion are computed, then the performance value of each alternative, namely the values that each alternative has for each criterion, is aggregated with the criteria weights. Sometimes this procedure can be implemented in a subjective manner. In this case, decision makers who are experts with sufficient knowledge and experience as to the decision issue determine the selection results according to their personal assessments. They determine criteria weights based on their point of views. Next, these subjective assessments are aggregated using different mathematical procedures. Finally, the aggregated result is integrated with the performance values of alternatives. Provided that there are sufficient real data, criteria weights computing and determining alternative's rankings can be made without benefiting from experts' subjective opinions. This provides objectivity and especially more eligible results.

In this context, this study proposes an objective approach to solve material selection problem based on MCDM structure. For this purpose, Criteria Importance Through Intercriteria Correlation (CRITIC) and Multi-Attribute Ideal-Real Comparative Analysis (MAIRCA) integration is suggested. These are two of MCDM approaches that can be utilized with real data of alternatives and criteria. CRITIC was first advanced by Diakoulaki et al. in 1995 [14]. MAIRCA was first developed by Gigović et al. in 2014 [15]. In this study, CRITIC is selected to compute criteria weights, MAIRCA was selected to obtain rankings of alternatives. The reason to select CRITIC is to see the direction and strength of relations between criteria. Additionally, the differentiation amount between the value of each criterion according to the alternatives can be reflected to selection process. The reason for choosing MAIRCA for ranking alternatives, is for the purpose of giving equal chance to all alternatives at the beginning of the selection process and differentiating rankings of alternatives according to their performance values for each criterion [15]. Furthermore, the proposed approach can model criteria according to their nature as benefit and cost type. In selection process, some criteria are required to have lower values and some are required to have higher values. Criteria that are expected to have lower values are named as cost type, and the others are called as benefit type. For material selection, this classification is important for microstrip antenna.

18 different material alternatives were evaluated considering three different criteria which are dielectric constant, loss tangent and thermal expansion coefficient. These 18 materials are selected due to the fact that these materials are among the main group that consists of composite materials, ceramic materials and polymeric materials which are prominent candidate materials for antenna manufacturing. Eventually the best material for microstrip antenna was determined. This study has an originality in the sense that it provides a new point of view in terms of material selection for microstrip antenna. By considering more than one different criteria, material selection for microstrip antenna can be made considering only performance value of each criterion for microstrip antenna, without the necessity of performing experimental procedures. Additionally, CRITIC and MAIRCA integration has not been used in the microstrip antenna material selection.

The remaining parts of this paper are organized as follows. In the second section, literature review related to material selection for microstrip antenna together with applications related to CRITIC and MAIRCA are given. In the third section, the implementation steps of the proposed approach are explained. Fourth section of the study includes application of the proposed approach for microstrip antenna material selection. Fifth section of the study covers results, discussion and future study options. There is a limited number of studies in literature related to CRITIC. Information about these studies are presented in detail in the following lines. CRITIC Technique was performed for Order Preference by

Similarity to Ideal Solution (TOPSIS) to prioritize water-saving irrigation schemes for the aim of making decision related to the best water-saving irrigation scheme [16]. Ping (2011) used CRITIC to evaluate the medical service quality of hospital departments [17]. Kazan and Özdemir (2014) compared financial performances of 14 holdings [18]. In addition, 19 financial ratios between 2009-2010 were considered for these holdings [18]. The weights of 19 financial ratios were computed via using CRITIC and the rankings of holdings were obtained by TOPSIS [18]. In another study, the business intelligence levels of companies is evaluated by performing CRITIC and TOPSIS integration [19]. It was decided which railway connection should be constructed primarily among 78, via implementing CRITIC, Standard Deviation and Mean Weight approaches to compute criteria weights [20]. Then, TOPSIS and Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR) was utilized to rank 78 railway connections [20]. In the final part of the study, two different ranking results of TOPSIS and VIKOR obtained, were combined by Borda Counting Method [20]. The criteria was weighted that effect human development levels of countries by Entropy and CRITIC [21]. Country rankings were determined by Grey Relational Analysis (GRA) and Multi-Objective Optimization on the basis Ratio Analysis (MOORA)[21]. The performances of firms in Exchange İstanbul 30 Index were compared by implementing CRITIC and TOPSIS [22].

Examination of literature on MAIRCA, reveals that very few studies have been conducted in this field. Gigović et al. (2016) combined Geographic Information System (GIS) with MCDM for location selection problem for ammunition depots [15], where six regions were evaluated by considering nine criteria [15]. Decision Making Trial and Evaluation Laboratory—Analytic Network Process (DEMATEL-ANP) integration was performed to compute criteria weights [15]. To rank six regions, MAIRCA was utilized [15]. Pamucar et al (2017) proposed a new approach based on DEMATEL-ANP-MAIRCA integration based on interval rough numbers to model uncertainties in decision processes [23]. The proposed method has been used in the public tender procedure realized by the government in the selection process of willing companies [23]. Obtained results from the study were compared with the results produced by TOPSIS, VIKOR, Multi Attribute Comparison of Border Approximate Area (MABAC), Iterative Multi Criteria Decision Making (TODIM), Elimination and Choice Translating Reality English (ELECTRE I) and fuzzy version of DEMATEL-ANP integration [23]. Moreover, the Best-Worst method (BWM) and MAIRCA were integrated based on rough numbers [24]. The proposed approach was used for supplier selection [24]. Furthermore, Chattarjee et al. (2018) performed DEMATEL, ANP and MAIRCA by integrating rough numbers [25]. The difference in the ranking of alternatives was focused via changing criteria weights [25].

As seen from the literature review, researchers have not performed CRITIC-MAIRCA integration and have not used this integration for microstrip antenna selection. Additionally, none of the MCDM approaches have not been performed for material selection related to the microstrip antenna. Consequently it is possible to come to the conclusion that this paper has the potential to provide new insights and considerable contributions to the literature on microstrip antenna.

## **2. MATERIALS AND METHOD**

In this study, CRITIC-MAIRCA integration is proposed to select the best material alternative for microstrip antenna. Therefore, CRITIC is performed at the first stage to obtain impact levels as a weights of criteria and at the second stage, results of CRITIC are used to find the best material alternative by ranking materials with MAIRCA. The application of the proposed approach is given below step by step.

### ***First stage: Determining weights of criteria***

CRITIC used in this study to compute weights of criteria was first developed by Diakoulaki et al. (1995) [14]. The implementation steps of CRITIC are given below [14,20,26].

**Step 1.1. Construct initial decision matrix.**

Initial decision matrix shows the performance values of alternatives according to criteria. Each alternative has a different value for each criterion and these values are named as performance values. According to these values alternatives have certain ranks at the end of decision process. Initial decision matrix is denoted as  $[X]$  and each element of  $[X]$  is indicated as  $x_{ij}; i = 1, \dots, m$  and  $j = 1, \dots, n$ .  $x_{ij}$  is the performance value of  $i$ th alternative for  $j$ th criterion. Each criterion is represented by  $C_j; j = 1, \dots, n$  and each alternative is depicted as  $A_i; i = 1, \dots, m$ .  $[X]$  is given in Eq.(1).

$$X = [x_{ij}]_{m \times n} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \quad (1)$$

**Step 1.2. Normalize the initial decision matrix.**

Criteria considered in selection process may sometimes be cost type, and other times benefit type. Cost type criteria are always intended to take low values. The alternative which has the lowest value in terms of any cost type criterion is the best alternative for this criterion compared to others. On the other hand, benefit type criteria are intended to take high values. The alternative which has the highest value in terms of any benefit type criterion is the best alternative compared to others. Therefore there are two different normalization processes in CRITIC; normalization for cost type criteria as in Eq.(2) and normalization for benefit type criteria as in Eq.(3).

For cost type criteria

$$b_{ij} = \frac{x_j^{max} - x_{ij}}{x_j^{max} - x_j^{min}} \quad (2)$$

For benefit type criteria

$$b_{ij} = \frac{x_{ij} - x_j^{min}}{x_j^{max} - x_j^{min}} \quad (3)$$

where;

$b_{ij}$ : normalized value of  $j$ th criterion according to  $i$ th alternative

$x_j^{min}$ : the minimum value of  $j$ th criterion according to all alternatives

$x_j^{max}$ : the maximum value of  $j$ th criterion according to all alternatives

$b_{ij}$  values form normalized initial decision matrix  $[N]$ .

**Step 1.3. Compute the correlation between criteria and determine the total information for each criterion.**

Whether the criteria are related, has an effect on the preference of an alternative as a result of the selection process., For this reason, the direction and strength of the relationship must be determined with suitable statistical methods. This feature is one of the main advantages of CRITIC. To compute the direction and strength of the relationship between criteria, multiple correlations must be obtained from  $[N]$  as given in Eq. (4).

$$Sp_{jk} = 1 - \frac{6 \sum_{i=1}^m d_i^2}{n(n^2 - 1)}; j, k = 1, 2, \dots, n \quad (4)$$

where;

$S_{jk}$ : Correlation value between  $j$ th criterion and  $k$ th criterion. This value is computed using Spearman Correlation Coefficient.

The total information for each criterion  $S_j$  includes relationship between criteria and amount of change in criteria values for alternatives. Computation of  $S_j$  which is shown in Eq.(5), enables systematic evaluation of the data for criteria to make logical a selection.

$$S_j = \sigma_j \sum_{k=1}^n (1 - S_{jk}); j = 1, \dots, n \quad (5)$$

where;

$\sigma_j$ : standard deviation for  $j$ th criterion.  $\sigma_j$  is calculated as in Eq.(6).

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^m (r_{ij} - \bar{r}_{ij})^2}{m - 1}} \quad (6)$$

$\sigma_j$  shows the spread of the data relative to the arithmetic mean. A small deviation indicates that the values in a data group are close to each other. The larger the standard deviation, the higher the values in the data group. CRITIC has also the advantage of considering differentiation between criteria values.

#### **Step 1.4. Determine the criteria weights.**

Each criterion weight is denoted as  $w_j$  and obtained as in Eq.(7).

$$w_j = \frac{S_j}{\sum_{j=1}^n S_j} \quad (7)$$

Criteria weights effect the selection process. This weights are the impact of each criterion on the alternative that may be chosen. Especially, criterion with the highest weight has the highest impact on selection result.

#### **Second stage: Ranking alternatives**

Alternatives are the options that have different features or different performance values for each criterion of selection process. To rank alternatives in this study, MAIRCA was implemented. MAIRCA was first developed by Pamučar et al. (2014) [23]. MAIRCA depends on the determination of the difference between the theoretical and reel preference level of alternatives [15,23]. The implementation steps of MAIRCA are given below.

##### **Step 2.1. Construct the initial decision matrix.**

Initial decision matrix  $[X]$  was constructed in Step 1.1. as in Eq.(1). The same matrix is also used for MAIRCA. The performance values of alternatives for criteria are also important for MAIRCA.

##### **Step 2.2. Determine the selection probability of alternatives.**

The selection probability of each alternative is denoted as  $P_i$ .  $P_i$  has the same value for each alternative at the beginning of the selection process because at this stage, performance values of the alternatives are not taken into consideration. Therefore, each alternative is an ideal alternative. In this context,  $P_i$  for each alternative among  $m$  can be obtained as in Eq. (8).

$$P_i = \frac{1}{m}; \sum_{i=1}^m P_i = 1; i = 1, \dots, m \quad (8)$$

Where;

$m$  is the total number of alternatives and  $P_1 = P_2 = P_m$ .

**Step 2.3. Construct the theoretical evaluation matrix.**

Theoretical evaluation matrix is indicated as  $[T]$  and it includes weights of criteria obtained in Step 1.4. and the selection probability of each alternative. The element of  $[T]$  is denoted as  $t_{ij}$  ( $t_{ij} = P_i \times w_i$ ) which means the theoretic evaluation value of  $j$ th criterion for  $i$ th alternative.  $[T]$  is given in Eq. (9) and (10).

$$T = [t_{ij}]_{m \times n} = \begin{bmatrix} t_{11} & t_{12} & \dots & t_{1n} \\ t_{21} & t_{22} & \dots & t_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ t_{m1} & t_{m2} & \dots & t_{mn} \end{bmatrix} \quad (9)$$

$$T = [t_{ij}]_{m \times n} \begin{bmatrix} P_1 w_1 & P_1 w_2 & \dots & P_1 w_n \\ P_2 w_1 & P_2 w_2 & \dots & P_2 w_n \\ \vdots & \vdots & \vdots & \vdots \\ P_m w_1 & P_m w_1 & \dots & P_2 w_n \end{bmatrix} \quad (10)$$

**Step 2.4. Construct the reel evaluation matrix.**

Reel evaluation matrix is represented as  $[R]$ .  $[R]$  covers the element of  $[T]$  and the element of  $[N]$ . This matrix considers normalized performance values of each alternative for each criterion. For this reason, this matrix is named as reel evaluation matrix. In theoretical evaluation matrix reel performance values of alternatives are not taken into account.  $[R]$  is established as in Eq.(11).

$$R = [r_{ij}]_{m \times n} = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \dots & r_{mn} \end{bmatrix} \quad (11)$$

where;

$r_{ij}$  is the reel evaluation value of  $j$ th criterion for  $i$ th alternative. It is computed as in Eq.(12) and (13) for cost and benefit type criteria respectively.

For cost type criteria

$$r_{ij} = t_{ij} \times \frac{x_j^{max} - x_{ij}}{x_j^{max} - x_j^{min}} \quad (12)$$

For benefit type criteria

$$t_{ij} = t_{ij} \times \frac{x_{ij} - x_j^{min}}{x_j^{max} - x_j^{min}} \quad (13)$$

**Step 2.5. Form the gap matrix.**

The gap matrix denoted as  $[G]$  considers difference between theoretical evaluation value and reel evaluation value of each alternative. The element of  $[G]$  is represented as  $g_{ij}$  which means the gap value of  $j$ th criterion for  $i$ th alternative.  $[G]$  is shown in Eq.(14).

$$G = [g_{ij}]_{m \times n} \begin{bmatrix} t_{11} - r_{11} & t_{12} - r_{12} & \cdots & t_{1n} - r_{1n} \\ t_{21} - r_{21} & t_{22} - r_{22} & \cdots & t_{2n} - r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ t_{m1} - r_{m1} & t_{m2} - r_{m2} & \cdots & t_{mn} - r_{mn} \end{bmatrix} \quad (14)$$

The gap value for each alternative shows the degree of disparity of an alternative to be a candidate for each criterion, when the performance values are taken into consideration.

**Step 2.6. Compute function value for each criterion.**

The criterion function value represented as  $Q_i$  is computed using Eq.(15).

$$Q_i = \sum_{j=1}^n g_{ij}; i = 1, \dots, m \quad (15)$$

$Q_i$  is also named as total gap for each alternative. If the total gap value is larger, the related alternative is less likely to be a selected candidate. For this reason, alternatives are ranked in a descending order to determine the best alternatives. The alternative which has the lowest  $Q_i$  value is the best alternative.

**Implementation of the proposed approach to select the best material for microstrip antenna**

The proposed approach was applied to determine the best material for microstrip antenna as given below according to the steps of the suggested approach.

**First stage: Determining weights of criteria**

In this stage, the application steps of CRITIC were utilized in microstrip antenna material selection process to determine the most effective criterion for this process.

**Step 1.1. Construct initial decision matrix.**

To select the suitable material for microstrip antenna three criteria  $C_j; j = 1, \dots, 3$  as dielectric constant ( $C_1$ ), loss tangent ( $C_2$ ) and thermal expansion coefficient ( $C_3$ ) are considered. 18 different material alternatives  $A_i; i = 1, \dots, 18$  are evaluated in terms of these three criteria. Table 1 shows the material definitions, related resources the three criteria for all alternatives and how thermal expansion coefficient criterion was obtained. The initial decision matrix  $[X]$  was established by the help of performance values of 18 alternatives according to three criteria ( $x_{ij}$ ) as in Eq.(1).  $[X]$  for material selection is given in Table 2.



**Table 1.** Detailed information for material alternatives and criteria

Alternatives ( $A_i$ )	Material	Dielectric constant	Loss tangent	Thermal expansion coefficient (1/°C)	
$A_1$	RT/duroid-5880 PTFE	2.07 [27]	0.0015[27]	$4*10^{-5}$ [28]	√
$A_2$	Epoxy unreinforced	5.7 [29]	0.018 [29]	$6.1*10^{-5}$ [30]	Graph √
$A_3$	Epoxy - glass	4.93 [31]	0.046 [31]	$2.61*10^{-5}$ [32]	Graph √
$A_4$	Epoxy-5wt% AlN	6.52 [33]	0.013 [33]	$66.5*10^{-6}$ [34]	Graph √
$A_5$	Epoxy-40wt% AlN	7.58 [33]	0.012 [33]	$48.5*10^{-6}$ [34]	Graph √
$A_6$	PTFE unreinforced	2.1 [13][35]	0.0004 [9]	( $39*10^{-5}$ ) [36], ( $10.9*10^{-5}$ ) [35] ( $20*10^{-5}$ ) [28] ( $20.7*10^{-5}$ ) [32]	√
$A_7$	PTFE-glass random fiber (30%)	2.17 [9]	0.0009[9]	$3.93*10^{-3}$ [37]	√
$A_8$	Polystyrene -alumina ceramic powder (10%)	2.62 [9]	0.001[9]	$6.37*10^{-5}$	Calculated by law of mixtures: $0.10*(7.4*10^{-6})$ [38]+ $0.90*(0.7*10^{-4})$ [39] graph = $6.37*10^{-5}$
$A_9$	Silicon resin-alumina ceramic powder (10%)	3 to 25 [9]	from 0.0005[9]	0.0737	Calculated by law of mixtures: $0.10*(7.4*10^{-6})$ [38]+ $0.90*(0.0819)$ [38] = 0.0737
$A_{10}$	Alumina ceramic	9.7 to 10.3 [9]	0.0004[9]	$7.4*10^{-6}$ [38]	√
$A_{11}$	27wt% SrTiO <sub>3</sub> (micro-size)-PEEK	5.27 [13]	0.0037[13]	0.0104	Calculated by law of mixtures: $0.27*(881.79*10^{-5})$ [40] + $0.73(0.01092)$ [37] = 0.0104
$A_{12}$	27wt% SrTiO <sub>3</sub> (nano-size)-PEEK	5.9 [13]	0.0278[13]	$2.85*10^{-6}$	Same as 27wt% SrTiO <sub>3</sub> (micro-size)-PEEK
$A_{13}$	BaSrTi <sub>2</sub> O <sub>6</sub> (bulk form) (40 SrO:TiO <sub>2</sub> , 60 BaO:TiO <sub>2</sub> ) [41]	5160.64 [41],	0.00961 [41]	$9.18*10^{-5}$ [42]	Calculated from % shrinkage
$A_{14}$	BaSrTi <sub>2</sub> O <sub>6</sub> (bulk form) (29 SrO:TiO <sub>2</sub> , 71 BaO:TiO <sub>2</sub> ) (denoted by SB 29 [42])	6000 [42]	~ 0.0043 [43]	$9.18*10^{-5}$ [42]	Same as A <sub>13</sub>
$A_{15}$	BaSrTi <sub>2</sub> O <sub>6</sub> (tape form)	3192.2 [41]	0.0056 [41]	$9.18*10^{-5}$ [42]	Calculated from % shrinkage
$A_{16}$	60wt%MgO- BaSrTi <sub>2</sub> O <sub>6</sub> (bulk form)	116.86 [41]	0.00148 [41]	$3.50*10^{-3}$	Calculated by law of mixtures $0.6*(9.18*10^{-5})$ [42] + $0.4*(860*10^{-5})$ [44] = $3.50*10^{-3}$
$A_{17}$	60wt%MgO- BaSrTi <sub>2</sub> O <sub>6</sub> (tape form)	91.16 [41]	0.0008 [41]	$3.50*10^{-3}$	Same as 60wt%MgO- BaSrTi <sub>2</sub> O <sub>6</sub> (bulk form)
$A_{18}$	LCP	3.08 [45], 3.16 [11]	0.0049 [11]	$<4*10^{-5}$ [11]	√

As seen from Table 2, dielectric constant value for Silicon resin-alumina ceramic powder (10%) can change from 3 to 25. For this reason, to obtain a represented value, mean of this range is used as 14. In the same manner, dielectric constant value for LCP was considered as 3.12. In term of thermal expansion coefficient for PTFE unreinforced material  $22.65 \times 10^{-5}$  was used as an average.

**Table 2.** Initial decision matrix for material selection

Alternatives ( $A_i$ )	Criteria ( $C_j$ )		
	$C_1$	$C_2$	$C_3$
	$x_{i1}$	$x_{i2}$	$x_{i3}$
$A_1$	2.07	0.0015	0.000004
$A_2$	5.7	0.018	0.000061
$A_3$	4.93	0.046	0.0000261
$A_4$	6.52	0.013	0.0000665
$A_5$	7.58	0.012	0.0000485
$A_6$	2.1	0.0004	0.0002265
$A_7$	2.17	0.0009	0.00393
$A_8$	2.62	0.001	0.0000637
$A_9$	14	0.0005	0.0737
$A_{10}$	10	0.0004	0.0000074
$A_{11}$	5.27	0.0037	0.0104
$A_{12}$	5.9	0.0278	0.00000285
$A_{13}$	5160.64	0.00961	0.0000918
$A_{14}$	6000	0.0043	0.0000918
$A_{15}$	3192.2	0.0056	0.0000918
$A_{16}$	116.86	0.00148	0.0035
$A_{17}$	91.16	0.0008	0.0035
$A_{18}$	3.12	0.0049	0.00004

**Step 1.2. Normalize the initial decision matrix.**

Among the criteria under consideration, only dielectric constant ( $C_1$ ) is benefit type criterion where, loss tangent ( $C_2$ ) and thermal expansion coefficient ( $C_3$ ) are cost type criteria. For this reason, Eq.(2) was used to normalize performance values of alternatives related to dielectric constant ( $C_1$ ) and loss tangent ( $C_2$ ), which briefly implies implementation of cost type normalization. Eq.(3) is adopted for normalizing performance values of alternatives, related to dielectric constant ( $C_1$ ) as a benefit type normalization. These normalized values formed Normalized Initial Decision Matrix for material selection as in Table 3.

**Table 3.** Normalized initial decision matrix for material selection

Alternatives ( $A_i$ )	Criteria ( $C_j$ )		
	$C_1$	$C_2$	$C_3$
	$b_{i1}$	$b_{i2}$	$b_{i3}$
$A_1$	0.00000000	0.9758772	1.0000000
$A_2$	0.00060521	0.6140351	0.9992266
$A_3$	0.00047683	0.0000000	0.9997001
$A_4$	0.00074192	0.7236842	0.9991519
$A_5$	0.00091865	0.7456140	0.9993962
$A_6$	0.00000500	1.0000000	0.9969808
$A_7$	0.00001667	0.9890351	0.9467271
$A_8$	0.00009170	0.9868421	0.9991899
$A_9$	0.00198902	0.9978070	0.0000000
$A_{10}$	0.00132212	1.0000000	0.9999539
$A_{11}$	0.00053352	0.9276316	0.8589340
$A_{12}$	0.00063855	0.3991228	1.0000156
$A_{13}$	0.86005839	0.7980263	0.9988086
$A_{14}$	1.00000000	0.9144737	0.9988086
$A_{15}$	0.53187183	0.8859649	0.9988086
$A_{16}$	0.01913827	0.9763158	0.9525619
$A_{17}$	0.01485346	0.9912281	0.9525619
$A_{18}$	0.00017506	0.9013158	0.9995115

**Step 1.3. Compute the correlation between criteria and determine the total information for each criterion.**

To compute the direction and strength of the relationship between three considered criteria, Eq. (4) is used and the multiple correlation table is given in Table 4.

**Table 4.** Multiple correlation table for three criteria

Criteria ( $C_j$ )	$C_1$	$C_2$	$C_3$
$C_1$	1.000	-0.980	-0.257
$C_2$	-0.980	1.000	-0.476
$C_3$	-0.257	-0.476	1.000

\*. -0,476 Correlation is significant at the 0.05 level (2-tailed).

According to the Table 3, there is a strong negative relation between dielectric constant ( $C_1$ ) and loss tangent ( $C_2$ ). Briefly, if the value of dielectric constant increase, the value of loss tangent decrease. In the same manner, there is also a negative relation between dielectric constant ( $C_1$ ) and thermal expansion coefficient ( $C_3$ ). Additionally, another negative relation is in between loss tangent ( $C_2$ ) and thermal expansion coefficient ( $C_3$ ). Finally, there is also a negative relation between thermal expansion coefficient ( $C_3$ ) and dielectric constant ( $C_1$ ).

The total information for each criterion  $S_j$  was computed using Eq.(5).  $S_j$  and  $\sigma_j$  values are given in Table 5.

**Table 5.** The total information and standard deviation for each criterion

Criteria ( $C_j$ )	$\sigma_j$	$S_j$
$C_1$	0.31568832	1.0218831
$C_2$	0.26226975	0.9064042
$C_3$	0.23432183	0.6404016

As evident from Table 4, the highest differentiation criteria values for alternatives occur in the first criterion. This means that, predetermined material alternatives have different dielectric constant values. Therefore, dielectric constant value will be the decisive criterion for the selection process. Additionally, the total information value related to this criterion is higher than the other criteria. This also shows that decisive feature of this criterion for microstrip antenna.

**Step 1.4. Determine the criteria weights.**

Each criterion weight ( $w_j$ ) seen in Table 6 was obtained as in Eq.(7).

**Table 6.** Weight of each criterion for material selection

Criteria ( $C_j$ )	Criteria weights $w_j$
$C_1$	0.397822833
$C_2$	0.352866494
$C_3$	0.249310673

As mentioned before, criteria weights have impacts on the result of selection process. Table 5 shows that dielectric constant ( $C_1$ ) has the highest importance weight for material selection process. This means that dielectric constant has the highest impact to select material related to microstrip antenna. This differentiation helps to determine the best material alternative.

**Second stage: Ranking alternatives**

In this stage, the utilization steps of MAIRCA were performed microstrip antenna material selection process to identify the best material for microstrip antenna.

**Step 2.1. Construct the initial decision matrix.**

Initial decision matrix  $[X]$  was constructed in Step 1.1 for microstrip antenna material selection as in Eq.(1). The same matrix is also used for MAIRCA.

**Step 2.2. Determine the selection probability of alternatives.**

In microstrip antenna material selection process, as mentioned before, there are 18 different material alternatives so, the selected candidate of each material ( $P_i$ ) is computed as  $\frac{1}{18} = 0,5556$  by using Eq. (8).

**Step 2.3. Construct the theoretical evaluation matrix.**

Theoretical evaluation matrix which is indicated by  $[T]$  was formed implementing Eq. (9) and (10) for material selection process. In this matrix, for each material, probability of being selected ( $P_i$ ) at initial phase of the selection process and the impact level of each criterion ( $w_i$ ) were considered.  $[T]$  is given in Table 7.

**Table 7.** Theoretical evaluation matrix of material selection process

Alternatives ( $A_i$ )	Criteria ( $C_j$ )		
	$C_1$	$C_2$	$C_3$
	$t_{i1}$	$t_{i1}$	$t_{i1}$
$A_1$	0.022101269	0.019603694	0.013850593
$A_2$	0.022101269	0.019603694	0.013850593
$A_3$	0.022101269	0.019603694	0.013850593
$A_4$	0.022101269	0.019603694	0.013850593
$A_5$	0.022101269	0.019603694	0.013850593
$A_6$	0.022101269	0.019603694	0.013850593
$A_7$	0.022101269	0.019603694	0.013850593
$A_8$	0.022101269	0.019603694	0.013850593
$A_9$	0.022101269	0.019603694	0.013850593
$A_{10}$	0.022101269	0.019603694	0.013850593
$A_{11}$	0.022101269	0.019603694	0.013850593
$A_{12}$	0.022101269	0.019603694	0.013850593
$A_{13}$	0.022101269	0.019603694	0.013850593
$A_{14}$	0.022101269	0.019603694	0.013850593
$A_{15}$	0.022101269	0.019603694	0.013850593
$A_{16}$	0.022101269	0.019603694	0.013850593
$A_{17}$	0.022101269	0.019603694	0.013850593
$A_{18}$	0.022101269	0.019603694	0.013850593

As seen form Table 6 all material alternatives have the same theoretical evaluation value for each criterion. This is due to the fact that each alternative for each criteria has the equal selection probability and the weight of the same criterion is valid for each alternative.

**Step 2.4. Construct the reel evaluation matrix**

Reel evaluation matrix  $[R]$  for material selection was established as in Eq.(11) by using Eq.(12) and (13). This matrix includes, the performance values of predetermined materials for microstrip antenna, the impacts of criteria and the probability of being selected for each material  $[R]$  is given in Table 8.

**Table 8.** Reel evaluation matrix of material selection process

Alternatives ( $A_i$ )	Criteria ( $C_j$ )		
	$C_1$	$C_2$	$C_3$
	$r_{i1}$	$r_{i2}$	$r_{i3}$
$A_1$	0.0000000	0.0191308	0.0138506
$A_2$	0.0000134	0.0120374	0.0138399
$A_3$	0.0000105	0.0000000	0.0138464
$A_4$	0.0000164	0.0141869	0.0138388
$A_5$	0.0000203	0.0146168	0.0138422
$A_6$	0.0000001	0.0196037	0.0138088
$A_7$	0.0000004	0.0193887	0.0131127
$A_8$	0.0000020	0.0193458	0.0138394
$A_9$	0.0000440	0.0195607	0.0000000
$A_{10}$	0.0000292	0.0196037	0.0138500
$A_{11}$	0.0000118	0.0181850	0.0118967
$A_{12}$	0.0000141	0.0078243	0.0138508
$A_{13}$	0.0190084	0.0156443	0.0138341
$A_{14}$	0.0221013	0.0179271	0.0138341
$A_{15}$	0.0117550	0.0173682	0.0138341
$A_{16}$	0.0004230	0.0191394	0.0131935
$A_{17}$	0.0003283	0.0194317	0.0131935
$A_{18}$	0.0000039	0.0176691	0.0138438

It can be seen from Table 8 that, the reel evaluation value of each alternative was different because the performance value of each material for microstrip antenna based on each criterion is different.

### Step 2.5. Form the gap matrix

The gap matrix,  $[G]$  given in Table 9 was structured as in Eq.(14).

**Table 9.** The gap matrix for material selection

Alternatives ( $A_i$ )	Criteria ( $C_j$ )		
	$C_1$	$C_2$	$C_3$
	$g_{i1}$	$g_{i2}$	$g_{i3}$
$A_1$	0.0221013	0.0004729	0.0000000
$A_2$	0.0220879	0.0075663	0.0000107
$A_3$	0.0220907	0.0196037	0.0000042
$A_4$	0.0220849	0.0054168	0.0000117
$A_5$	0.0220810	0.0049869	0.0000084
$A_6$	0.0221012	0.0000000	0.0000418
$A_7$	0.0221009	0.0002150	0.0007379
$A_8$	0.0220992	0.0002579	0.0000112
$A_9$	0.0220573	0.0000430	0.0138506
$A_{10}$	0.0220720	0.0000000	0.0000006
$A_{11}$	0.0220895	0.0014187	0.0019538
$A_{12}$	0.0220872	0.0117794	-0.0000002
$A_{13}$	0.0030929	0.0039594	0.0000165
$A_{14}$	0.0000000	0.0016766	0.0000165
$A_{15}$	0.0103462	0.0022355	0.0000165
$A_{16}$	0.0216783	0.0004643	0.0006570
$A_{17}$	0.0217730	0.0001720	0.0006570
$A_{18}$	0.0220974	0.0019346	0.0000068

Table 10 shows the gap value for each material for each selection criterion. According to the dielectric constant ( $C_1$ ), PTFE unreinforced material ( $A_6$ ) has the highest gap value as 0,0221012. This means

that, when other alternatives are considered, the sixth alternative is considered as the least eligible material alternative for microstrip antenna according to the dielectric constant criterion.

### Step 2.6. Compute function value for each criterion

The criterion function values ( $Q_i$ ) and ranking of each material alternative depicted in Table 10 was computed as in Eq.(15).

**Table 10.** Function value for each material

Alternatives ( $A_i$ )	Function values ( $Q_i$ )	Rankings
$A_1$	0.0225742	7
$A_2$	0.0296649	15
$A_3$	0.0416986	18
$A_4$	0.0275134	14
$A_5$	0.0270762	13
$A_6$	0.0221430	5
$A_7$	0.0230537	10
$A_8$	0.0223684	6
$A_9$	0.0359509	17
$A_{10}$	0.0220727	4
$A_{11}$	0.0254620	12
$A_{12}$	0.0338664	16
$A_{13}$	0.0070688	2
$A_{14}$	0.0016931	1
$A_{15}$	0.0125982	3
$A_{16}$	0.0227996	9
$A_{17}$	0.0226020	8
$A_{18}$	0.0240387	11

As explained previously, function value of each alternative shows the total gap for each alternative. Table 10 shows that, Epoxy-glass ( $A_3$ ) has the highest gap value as 0,0416986 and it is at the eighteenth rank. This means that, epoxy-glass is not suitable as a material for microstrip antenna. On the other hand, BaSrTi<sub>2</sub>O<sub>6</sub> (bulk form) (29 SrO:TiO<sub>2</sub>, 71 BaO:TiO<sub>2</sub>) ( $A_{14}$ ) has the smallest total gap value as 0,0016931. Therefore, it came out as the best material alternative for microstrip antenna, considering dielectric constant ( $C_1$ ), loss tangent ( $C_2$ ) and thermal expansion coefficient ( $C_3$ ).

## 3. RESULTS AND DISCUSSION

In this study, CRITIC-MAIRCA integration is proposed to select the best material alternative for microstrip antenna. CRITIC is used for determining the impact levels of dielectric constant, loss tangent and thermal expansion coefficient criteria. MAIRCA is performed for ranking material alternatives in terms of these three criteria.

Ceramics are arising alternative materials for antenna material selection due to their superior electrical and thermal properties. Barium strontium titanium oxide (BaSrTi<sub>2</sub>O<sub>6</sub>) and its combinations with MgO, nonelectrically active oxide ceramic, in bulk and tape forms as alternatives 13, 14, 15, 16 and 17 were compared. The 1<sup>st</sup> and 2<sup>nd</sup> places in the ranking belong to BaSrTi<sub>2</sub>O<sub>6</sub> in bulk form (having %40 and %29 SrO:TiO<sub>2</sub> respectively) according to the decision matrix regarding the dielectric constant, loss tangent and the coefficient of thermal expansion. The only difference is the ratio of strontium titanate (SrO:TiO<sub>2</sub>) to barium titanate (BaO:TiO<sub>2</sub>) in BaSrTi<sub>2</sub>O<sub>6</sub>. The BaSrTi<sub>2</sub>O<sub>6</sub> in tape form took the 3<sup>rd</sup> place because in term of dielectric constant criterion as a benefit type criterion, the BaSrTi<sub>2</sub>O<sub>6</sub> in tape form has lower dielectric constant value than BaSrTi<sub>2</sub>O<sub>6</sub> in bulk form. As higher values are required and wanted for benefit type criteria, BaSrTi<sub>2</sub>O<sub>6</sub> in bulk form is preferred more, based on dielectric constant criterion. On the other hand, in terms of loss tangent criterion as a cost type criterion, BaSrTi<sub>2</sub>O<sub>6</sub> in bulk form has a lower value than the BaSrTi<sub>2</sub>O<sub>6</sub> in tape form. Lower values are required and favored for cost

type criteria, therefore in terms of loss tangent, BaSrTi<sub>2</sub>O<sub>6</sub> in bulk form is more preferable. These two materials have also equal thermal expansion coefficient values. According to the criteria impact levels, dielectric constant and loss tangent criteria have the highest effects on selection process. As a result, BaSrTi<sub>2</sub>O<sub>6</sub> in bulk form is ahead of BaSrTi<sub>2</sub>O<sub>6</sub> in tape form.

Addition of 60 wt% MgO in BaSrTi<sub>2</sub>O<sub>6</sub> increased the ranking level from 8 to 9. The result is compatible with the statement that oxide additions decreased the dielectric values [46]. Although most of the ceramic materials have high dielectric constant and low loss, sheet formation is not an option for these brittle materials [6]. Therefore, embedding ceramic particles in resins is an alternative to use ceramic as antenna materials. Thus, the added particles improve the electrical and thermal properties of the polymer matrix [47,48]. BN[49], AlN [33,49], Al<sub>2</sub>O<sub>3</sub> [9] and metal titanate [6,48] particles are the common ceramic particles that are distributed in polymer matrix. According to the study of Kochetov et. al., addition of 0.5 wt% AlN particles in epoxy, led to a decrease in dielectric constant but increased the particle content up to 2 wt%, 5 wt% and 10 wt% increased dielectric constant [49]. Therefore, alternatives 4 and 5 were selected to be 5 wt% and 10 wt% AlN particles distributed in epoxy and corresponding rankings are 14 and 13, respectively. Better results in ranking were observed by AlN addition compared to neat epoxy (15<sup>th</sup> place) and by increasing AlN content in epoxy. Alumina ceramic powders that are distributed in polystyrene has the 6<sup>th</sup> place. Silicone is generally used as a binder to keep the particles together [50] for which alternative 9 (Al<sub>2</sub>O<sub>3</sub> powder + Si resin) is an example. Al<sub>2</sub>O<sub>3</sub> powder + Si resin takes the 17<sup>th</sup> place in the ranking. However, the main disadvantage of ceramic particle distribution is the anisotropy that will also lead to high values of thermal expansion coefficients [35]. Therefore, sintered Al<sub>2</sub>O<sub>3</sub> alone can be used as antenna material that takes the 4<sup>th</sup> place in the ranking. However, the porosity amount in the sintered alumina is critical since the dielectric constant decreases by increasing the pore content [51]. Furthermore, the impurity content is another important factor since the alumina with very high purity exhibits low tangent loss [52]. Especially, the metal-TiO<sub>3</sub> compounds are preferred due to high dielectric constant [6]. Favored metals are Ba, Ca, Sr., Mg, Pb, Zr, Mn, Nd, Bi, Sn, and mixtures that gives BaTiO<sub>3</sub>, CaTiO<sub>3</sub> and SrTiO<sub>3</sub> [6]. Alternatives from 11 to 17 in Table 1 represent these materials. Number 12 in ranking is the 27wt% micro sized SrTiO<sub>3</sub> (< 5µm)-PEEK which is compatible with the claim of presenting SrTiO<sub>3</sub> as one of the best ceramic filler titanate material due to its electrical properties [6]. The size effect of SrTiO<sub>3</sub> particles can be observed when alternatives 11 and 12 are compared. Small particle sizes of ceramic particles that is less than 10 µm are generally preferred [48]. However, it was concluded that when the same metal titanate that is SrTiO<sub>3</sub> in nano size (< 100nm) is distributed in polymer matrix (PEEK), a different ranking was obtained. In conclusion, the nano sized SrTiO<sub>3</sub> distributed in PEEK took the 16<sup>th</sup> place. This can be attributed to the parameter values. However, in terms of dielectric constant value as a benefit type criterion, SrTiO<sub>3</sub> in nano size has the highest value, in terms of loss tangent criterion, the difference between micro sized SrTiO<sub>3</sub> and SrTiO<sub>3</sub> in nano size is greater. Micro sized SrTiO<sub>3</sub> has lower value than SrTiO<sub>3</sub> in nano size. As mentioned before, loss tangent has the second highest impact on selection process. Additionally, there is a strong and negative relation between dielectric constant and loss tangent. This negative strength relation decreases the rank of SrTiO<sub>3</sub> in nano size. Additionally, in terms of thermal expansion coefficient, micro sized SrTiO<sub>3</sub> has a higher value than nano sized but thermal expansion coefficient criterion has the lowest impact and there is a weak negative relation between thermal expansion coefficient and dielectric constant, and between thermal expansion coefficient and loss tangent. Alternative values for thermal expansion coefficient criterion have the lowest differentiation values. This means that all alternatives have close values for this criterion. For these reasons, SrTiO<sub>3</sub> in nano sized has a lower rank than the micro sized. Moreover, although it was claimed that decreasing particle size increases the dielectric constant [53] that is not the case in SrTiO<sub>3</sub> – PEEK composite despite the fact that it still supports the ranking result.

Glass fibers in polymer matrices are among the most preferred materials for antenna manufacturing. In addition, the chopped glass fibers and the soft nature of the polymers have the advantage of forming complex shapes besides the electrical properties [9]. Alternative 1 denoted by RT/duroid-5880 PTFE that is glass microfiber in PTFE takes the 7<sup>th</sup> place and alternative 7 that is glass random fiber having

available thickness in the range of 0.508 to 3.175 mm [9] takes 10<sup>th</sup> place. This result can be attributed to the homogeneous distribution of finer glass fibers. On the other hand, unreinforced PTFE (alternative 6) has a ranking of 5. In terms of loss tangent criterion, unreinforced PTFE has the lowest value. This value brings up unreinforced PTFE to an upper rank than RT/duroid-5880 PTFE and glass random fiber. However, in terms of dielectric constant criterion as a benefit type criterion, these three materials have nearly same value. As it was mentioned above, loss tangent has the second highest weight for material selection process. This implication level also increases the preference level of unreinforced PTFE compared to the others. In terms of thermal expansion coefficient criterion, RT/duroid-5880 PTFE has the lowest value in comparison with the glass random fiber and unreinforced PTFE. Unreinforced PTFE has the second lowest value for this criterion according to the RT/duroid-5880 PTFE. Thermal expansion coefficient criterion has the lowest weight of material selection process. For this reason, having the smallest value in terms of thermal expansion coefficient for RT/duroid-5880 PTFE does not bring it to upper ranks. Additionally, thermal expansion coefficient has the weakest relation between the other two criteria and the differentiation value of alternatives for this criterion is smaller than differentiation amount of the dielectric constant and loss tangent. This weak relation and small differentiation result in, descending of RT/duroid-5880 PTFE to lower ranks.

Furthermore, the type of polymer matrix of composite materials plays an important role on the electrical properties. For instance, embedding glass fiber in PTFE result in a smaller loss tangent than in epoxy matrix [54]. Glass fiber embedded in epoxy (c3) was selected as the worst alternative (18). However, it is claimed that glass fiber-epoxy composites are used as antenna material because of the reduced cost of manufacturing, easy fabrication and market availability [54].

11<sup>th</sup> place belongs to LCPs which are arising materials for antenna production. The thermal expansion coefficient values were said to be lower than  $4 \cdot 10^{-5}/^{\circ}\text{C}$  but the maximum value was taken to study the worst scenario for the material. Decreasing this value will improve the ranking results.

This study provides a practical approach for material selection related to microstrip antenna manufacturing. To the best of our knowledge none of the studies in the literature perform CRITIC-MAIRCA integration for this purpose. This study uses real performance values of alternatives for all the criteria considered and suggests an objective evaluation and selection methodology.

For future studies, results of this paper which provides an initial foresight to determine the suitable material for microstrip antenna manufacturing, may be supported by experimental results. The proposed integrated approach can be used for other selection areas related to microstrip antenna manufacturing such as machine selection.

### 3. CONCLUSION

Ceramic and composite materials are important candidate materials for microstrip antenna manufacturing. Candidate materials were selected from these material groups and required properties were listed. CRITIC-MAIRCA integration which is one of the MCDM approaches, is carried out to determine the most suitable material for manufacturing microstrip antenna. In conclusion, the first three rankings were occupied by BaSrTi<sub>2</sub>O<sub>6</sub> in all amounts and forms, which rendered it the best material. Alumina ceramic, unreinforced PTFE and alumina- polystyrene composite material are stated as the following best candidates.

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